Open total aortic arch reconstruction for patients with advanced age in the era of endovascular repair

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Background: The aim of this study is to evaluate the influence of advanced age on the postoperative course in open aortic arch repair using hypothermic circulatory arrest and selective antegrade cerebral perfusion.

Methods: Of 158 consecutive patients who underwent open total arch repair between 2008 and 2012, we retrospectively compared outcomes between octogenarians (group E: mean age, 83.0 ± 3.1 years [n = 40]) and their younger counterparts (group Y: mean age, 68.2 ± 10.2 years [n = 118]), and evaluated risk factors for an adverse postoperative course.

Results: The overall 30-day mortality was 7.0% (11/158), and by excluding 54 emergent cases, 30-day mortality was 4.8% (5/104). Ruptured cases were significantly observed in group E (17.5% [7/40] vs 3.4% [4/118]; *P* = .006). There were no significant differences in postoperative early results, including neurologic adverse events (12.5% [5/40] vs 6.8% [8/118]; *P* = .317) and 30-day death (12.5% [5/40] vs 5.1% [6/118]; *P* = .147) between groups E and Y. Multivariate logistic analysis revealed rupture, preoperative consciousness disorder, and extended circulatory arrest time (≥67 minutes) were risk factors for serious complications (neurologic adverse events and 30-day death) (odds ratio [OR], 10.9 [*P* = .010]; OR, 5.2 [*P* = .040]; and OR, 3.5 [*P* = .028], respectively). A ruptured aorta was detected as an independent predictor of postoperative extended intensive care unit and hospital stay by multivariate linear regression analysis (*P* = .001 and *P* = .007, respectively).

Conclusions: Advanced age was not associated with serious postoperative complications and adverse postoperative course. (J Thorac Cardiovasc Surg 2014;148:77-82)

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Longer life expectancy and various developments in medicine can increase the number of patients with advanced age who require the treatment of aortic aneurysms. A combination of hypothermic circulatory arrest (HCA) and selective antegrade cerebral perfusion (SACP) is an established option, and both the safety and efficacy have been verified in many reports.[1-5] However, advanced age is one of the most significant risk factors for fatal complications and high mortality in open aortic arch repair.[6-8] However, age was not reported to be associated with high mortality and neurologic adversity in surgical repair with HCA.[9] Although the indication for thoracic endovascular aortic repair has been expanding rapidly in this decade, the optimal strategy for the treatment of aortic arch disease in elderly patients has not been determined. In our institution, the average age of patients who underwent open total arch repair (TAR) was high (72 ± 11 years), and the aim of this study was to analyze early outcomes in octogenarians after open TAR with HCA and SACP, compared with their younger counterparts, and to evaluate risk factors for an adverse postoperative course.

PATIENTS AND METHODS

Between January 2008 and May 2012, 162 consecutive patients underwent open total aortic arch repair without using thoracic endovascular aortic repair at a single cardiovascular institute. Of these patients, 3 with infected aneurysm and 1 with inflammatory aneurysm were excluded. Of the remaining 158 patients, octogenarians included 40 (25%). We excluded patients with preoperative complete unconsciousness and extremely low activities of daily living as candidates for open TAR.

Preoperative consciousness disorder was defined as transient neurologic disorder within 24 hours before operation, and patients with recovery from consciousness disorder were included as candidates. We retrospectively compared early outcomes between a contemporary series of patients 80 years or older (group E: n = 40) and younger than 80 years (group Y: n = 118) who underwent open TAR with HCA and SACP. This study was approved by the institutional review board.

Surgical Technique

After general anesthesia and intubation, transesophageal echocardiography and transcutaneous cerebral oximetry (INVOS 3100-SD; Somanetics Co, Troy, Mich) monitoring were routinely performed. Skin incision was made as shortly as possible for median sternotomy, and an incision of less than 20 cm was found in 56 patients (35%). The femoral artery and bicaval

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Abbreviations and Acronyms

CI	= confidence interval
CPB	= cardiopulmonary bypass
eCCr	= estimated creatinine clearance
HCA	= hypothermic circulatory arrest
ICU	= intensive care unit
OR	= odds ratio
SACP	= selective antegrade cerebral perfusion
TAR	= total arch repair

cannulations were used to establish cardiopulmonary bypass (CPB). The right or left axillary artery was mainly added in the patients with aortic dissection or severe atherosclerosis. In patients with severe atherosclerosis in the aorta, femoral artery perfusion was mainly used to flush out debris after open distal anastomosis. Left atrial venting was initiated through the right upper pulmonary vein. Exposures of 3 cerebral branches and distal arch were comfortably achieved by using the Martin Arm Retractor (LTL Medical LLC, Simi Valley, Calif). After cooling to 25°C for circulatory arrest, cardiac arrest was achieved by antegrade and selective deliveries of cardioplegic solution into both coronary orifices, and SACP was established by inserting balloon catheters into the 3 cerebral branches. When cannulation of the right axillary artery was used, the brachiocephalic artery was clamped for cerebral perfusion without using a balloon catheter. The distal aortic arch was separated off completely at the borderline between the lesion and normal aorta, and a stepwise technique was generally used for distal anastomosis in 90 patients (57%). We directly anastomosed with a 4-branched prosthetic graft, if at all possible, by using 3 different techniques (Figure 1, *A* to *C*).[10] We selected the optimal technique by the etiology, size of aneurysm, and intraoperative working space. After antegrade perfusion from the branch of the graft was restarted, the left subclavian artery was subsequently reconstructed. Typically, after proximal anastomosis to the aorta was performed and coronary perfusion was restarted, the left common carotid artery and the brachiocephalic artery were reconstructed in order (119 patients [75%]). However, when cardiac arrest time was prolonged, proximal anastomosis to the aorta was performed before reconstruction of 3 cerebral vessels (12 patients [8%]). However, in the patients with a normal ascending aorta and without a deeply located left subclavian artery, proximal anastomosis of a branched graft to the aorta was initially performed under aortic clamp during a cooling period. Subsequently, the distal aorta and 3 cerebral vessels were reconstructed in order (27 patients [17%]).

Statistical Analysis

Continuous data were presented as mean ± SD, and were analyzed using 2-tailed *t*-tests or compared with a Mann-Whitney test for independent data, as appropriate. Categorical variables are given as a count and percentage of patients and compared using the χ^2 or Fisher exact test. The correlation between age and postoperative data was assessed using Pearson correlation coefficient. Multivariate linear regression analysis, including significant parameters detected by univariate analysis (at a significance level of $P < .1$), was used to evaluate the most significant determinants of postoperative length of intensive care unit (ICU) and hospital stay. Univariate analysis was performed on all variables to detect potential risk factors for postoperative serious adverse complications (permanent neurologic adverse events and postoperative 30-day death). In association with these complications, all continuous parameters were dichotomized at the 25th, 33rd, 50th, 66th, and 75th percentiles, and the percentile value with the lowest *P* value was chosen as the threshold for logistic regression analysis. The univariate predictors with $P < .1$ were selected by a stepwise method and entered into the multivariate logistic regression. $P < .05$ was considered significant. All data were analyzed using the Statistical Analysis Systems software JMP 9.0 (SAS Institute Inc, Cary, NC).

RESULTS

Patient Demographics

The mean patient age was 71.9 ± 11.0 (range, 35-92) years, and the average age was 83.0 ± 3.1 years in group E and 68.2 ± 10.2 years in group Y. Group E had a lower mean body surface area (1.53 ± 0.17 vs 1.66 ± 0.21 m^2; $P = .001$) and estimated creatinine clearance (eCCr; 51.6 ± 63.2 vs 70.8 ± 34.3 mL/min; $P < .001$) compared with group Y. Preoperative and postoperative creatinine clearance was estimated by using the Cockcroft-Gault formula. Regarding etiology, aortic dissection was mainly seen in group Y, and more ruptured cases were observed in group E. An emergency operation was performed in 54 patients (34%), with no significant difference between the 2 groups. The mean aortic insufficiency grade was greater in group E. A comparison of preoperative characteristics is shown in Table 1.

Operative Data

Although the average operative time was significantly shorter in group E, there were no significant differences in CPB, cerebral perfusion, circulatory arrest, and cardiac arrest time. More patients with axillary artery cannulation and use of elephant trunk were seen in group Y. Aortic valve replacement and coronary artery bypass grafting were mainly performed as a concomitant cardiac surgery (aortic valve replacement, 25 patients; and coronary artery bypass grafting, 38 patients). There were significantly more patients requiring concomitant cardiac surgery in group E. Table 2 shows a comparison of operative data between groups E and Y.

Postoperative Data

The overall 30-day mortality was 7.0% (11/158), and by excluding 2 ruptured cases who died within 24 hours after emergent operation, 30-day mortality was 5.7% (9/158). The overall in-hospital mortality was 8.9% (14/158). There were no significant differences in 30-day and in-hospital deaths (12.5% [5/40] vs 5.1% [6/118] [$P = .147$]; and 15.0% [6/40] vs 6.8% [8/118] [$P = .193$], respectively) between groups E and Y. Causes of death included 1 fatal arrhythmia, 2 infections, 1 low cardiac output, and 1 vascular related in group E and 1 bleeding, 2 infections, 1 neurologic event, 1 pneumonia, and 1 multiorgan failure in group Y. There was no significant difference in postoperative neurologic adverse events (12.5% [5/40] vs 6.8% [8/118] [$P = .317$]) and other severe complications between groups E and Y. In patients with elective and emergent operations (n = 104 and 54, respectively), neurologic adverse events occurred in 6 (5.8%) and 7 (13.0%), and 30-day death was found in 5 (4.8%) and 6 (11.1%), respectively. An emergent operation did not significantly correlate with neurologic adverse events and 30-day death ($P = .135$ and .188, respectively). Although postoperative eCCr was significantly lower in group E (33.0 ± 16.1 vs 53.3 ± 27.1 mL/min; $P < .001$), the change rate of eCCr between

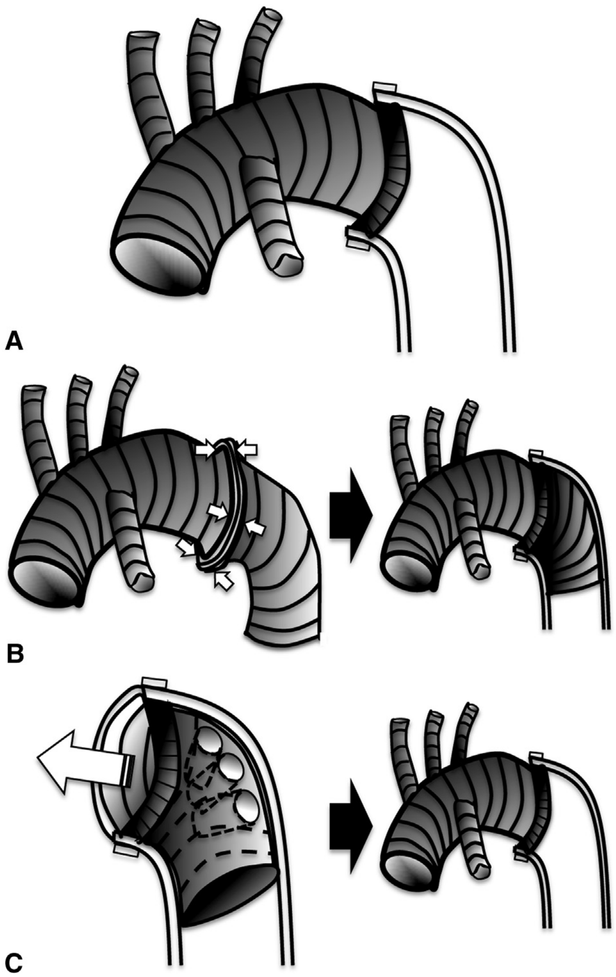

FIGURE 1. A, Direct anastomosis. Direct edge-to-edge anastomosis of 4-branched graft to the distal aortic arch. B, Direct anastomosis with elephant trunk. The flange was prepared by four 5-0 polypropylene mattress sutures (*white arrows*), and the distal anastomosis with elephant trunk was performed at the flange. The *black arrow* shows the 4-branched graft after distal anastomosis. C, Branched graft inversion. An inverted 4-branched graft was inserted to the distal arch. After the direct distal anastomosis was performed, the inverted graft was extracted (*white arrow*). The *black arrow* shows the 4-branched graft after distal anastomosis.

preoperation and postoperation was not significantly different (−23.4% ± 24.1% vs −21.5% ± 26.9%; $P = .923$). Table 3 shows a comparison of postoperative data between the 2 groups. Moreover, we evaluated the effects of age on the change rate of eCCr, initial ventilation times, length of ICU stay, and hospital stay. There were no significant correlations between age and all these parameters ($P = .537$, .443, .853, and .552, respectively) (Figure 2).

Risk Factors for Serious Adverse Complications

Permanent neurologic events and 30-day death were defined as postoperative serious adverse complications (n = 23). Advanced age (≥80 years) was not a significant factor for these serious complications (odds ratio [OR], 2.2; 95% confidence interval [CI], 0.8-5.4; $P = .113$). By univariate logistic analysis, a preoperative eCCr of less than 47.3 mL/min, emergency, rupture, preoperative consciousness disorder, operative time of 464 minutes or longer, CPB time of 196 minutes or longer, circulatory arrest time of 67 minutes or longer, and minimum body temperature of lower than 24°C were detected as perioperative risk with $P < .1$ factors for serious adverse complications. Multivariate analysis revealed that rupture (OR, 10.9; 95% CI, 1.8-78.7; $P = .010$), preoperative consciousness disorder (OR, 5.2; 95% CI, 1.1-24.8; $P = .040$), and circulatory arrest time of 67 minutes or longer (OR, 3.5; 95% CI, 1.1-12.1; $P = .028$) were independent risk factors for serious adverse complications (Table 4).

TABLE 1. Comparison of preoperative patients' data

Variable	Group E (n = 40)	Group Y (n = 118)	*P* value
Age, y	83.0 ± 3.1	68.2 ± 10.2	<.001
Female sex	10 (25)	40 (34)	.331
BSA, m^2	1.53 ± 0.17	1.66 ± 0.21	.001
Hypertension	33 (83)	97 (82)	1.000
Dyslipidemia	7 (18)	30 (25)	.390
Diabetes mellitus	3 (8)	10 (9)	1.000
COPD	3 (8)	7 (6)	.714
eCCr, mL/min	51.6 ± 63.2	70.8 ± 34.3	<.001
HD patient	1 (3)	5 (4)	1.000
Carotid stenosis	4 (10)	8 (7)	.501
Smoking	20 (50)	57 (48)	.857
AF	4 (10)	13 (11)	1.000
Cardiac disease	0 (0)	6 (5)	.339
Peripheral vascular disease	5 (13)	11 (9)	.554
Emergency	10 (25.0)	44 (37.3)	.181
Dissection	4 (10.0)	54 (45.8)	<.001
Ruptured aorta	7 (17.5)	4 (3.4)	.006
Preoperative consciousness disorder (within 24 h)	3 (7.5)	9 (7.6)	1.000
NYHA class	1.0 ± 1.2	1.0 ± 1.2	.771
LVEF, %	63.9 ± 10.9	64.5 ± 9.1	.862
AS	2 (5)	3 (3)	.602
AI grade (0-4)	1.4 ± 1.2	1.0 ± 1.1	.045

Data are given as mean ± SD or number (percentage). *BSA*, Body surface area; *COPD*, chronic obstructive pulmonary disease; *eCCr*, estimated creatinine clearance; *HD*, hemodialysis; *AF*, atrial fibrillation; *NYHA*, New York Heart Association; *LVEF*, left ventricular ejection fraction; *AS*, aortic stenosis; *AI*, aortic insufficiency.

Predictors of Postoperative Extended Length of ICU and Hospital Stay

To detect predictors of postoperative extended ICU and hospital stay, correlations with the postoperative ICU stay (days) and hospital stay (days) were analyzed. Two patients with death within 24 hours postoperation were excluded. By univariate linear regression, emergency, rupture, axillary artery cannulation, operative time, CPB time, and minimum body temperature were detected as correlated factors with

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TABLE 2. Comparison of operative data

Variable	Group E (n = 40)	Group Y (n = 118)	*P* value
Operative time, min	410 ± 67	458 ± 123	.040
CPB time, min	226 ± 37	238 ± 69	.729
Cerebral perfusion time, min	133 ± 24	135 ± 31	.778
Circulatory arrest time, min	65 ± 22	65 ± 16	.790
Cardiac arrest time, min	140 ± 28	145 ± 38	.482
Minimum BT, °C	24.1 ± 1.7	24.6 ± 1.7	.214
Axillary artery cannulation	14 (35)	68 (58)	.017
LSCA translocation	3 (8)	26 (22)	.057
ET	9 (23)	60 (51)	.002
Distal anastomosis technique			.067
Stepwise	21 (53)	69 (59)	
Direct anastomosis	5 (13)	23 (19)	
Direct anastomosis with ET	1 (3)	9 (8)	
Branched graft inversion	13 (33)	17 (14)	
Concomitant cardiac surgery	22 (55)	40 (34)	.024

Data are given as mean ± SD or number (percentage). *CPB*, Cardiopulmonary bypass; *BT*, body temperature; *LSCA*, left subclavian artery; *ET*, elephant trunk.

length of ICU stay, and similar variables, except CPB time, were isolated as correlated factors with length of hospital stay. Multivariate linear regression showed ruptured aorta was an independent predictor of postoperative extended length of both ICU and hospital stay (P = .001 and .007, respectively) (Table 5).

DISCUSSION

Given that the number of elderly patients requiring aortic arch repair is expected to increase, it is important to evaluate the influence of age on postoperative course and the outcomes of patients with extreme advanced age in open TAR. In open aortic arch repair, advanced age was reported to be a risk factor for postoperative mortality and prolonged ICU and hospital stay.[1,2,6-8] However, Czerny and colleagues[9] reported that age was not associated with increased risk for mortality and neurologic events. In their cohort, the average patient age was 64 years, and an age of 60 years and older was not a risk factor for serious complications. However, the number of patients older than 80 years was few (n = 8), and the mortality and neurologic event rates were high (37.5% and 25%, respectively). Pacini and colleagues[11] reported excellent results in 95 patients aged 75 years and older who underwent an elective aortic arch operation with SACP and HCA, whose occurrence rates of in-hospital death and permanent neurologic events were 7% and 5%, respectively. Tang and colleagues[12] reported excellent outcomes of 21 octogenarians who underwent surgical repair for type A aortic dissection (no hospital and late death), but there were no octogenarians who underwent TAR in their cohort. In addition, the efficacy of ascending and transverse aortic arch repair with profound HCA and retrograde cerebral perfusion in 37 octogenarians was reported by Shah and colleagues[13]: 30-day mortality, 13.5%; and stroke occurrence, 8%. Although these reports suggest good results of aortic surgical procedures in older patients, the outcomes of TAR with SACP and HCA in octogenarians are still controversial. In this study, a relatively higher percentage of 30-day mortality was found in octogenarians (12.5%), but the advanced age was not significantly associated with increased risk for postoperative serious adverse events regardless of preoperative greater percentage of rupture, lower eCCr, greater aortic insufficiency grade, and more concomitant surgery. Thirty-day mortality in patients aged 75 years and older was 9.2% (7/76). Regarding the relatively higher percentage of stroke in octogenarians, we routinely used femoral artery perfusion for flushing out debris in patients with severe atherosclerosis, yet the retrograde flow may have contributed to postoperative neurologic events (12.5%). Axillary artery cannulation was reported to reduce cerebral microembolism[14] and was performed in only 35% of patients in group E. Therefore, more accurate evaluation for selection of cannulation site may reduce risk of postoperative stroke. Of interest, age (mean age, 71.9 ± 11.0 years; range, 35-92 years) did not correlate with extended postoperative course. By multivariate analysis, preoperative consciousness abnormality, rupture, and extended circulatory arrest time (≥67 minutes) were detected as risk factors for postoperative adverse course, and ruptured aorta was an independent predictor of postoperative extended length of both ICU and hospital stay. To reduce HCA time, we directly performed distal anastomosis, if at all possible, by using 3 different techniques (Figure 1), and HCA time was significantly shorter in these techniques compared with the stepwise technique (61 ± 13 vs 68 ± 20 minutes; P = .026). Other risk factors indicated that preoperative conditions had a great impact on the postoperative early outcomes. To reduce the effects of HCA, SACP with mild to moderate

TABLE 3. Comparison of postoperative data

Variable	Group E (n = 40)	Group Y (n = 118)	*P* value
30-d death	5 (12.5)	6 (5.1)	.147
In-hospital death	6 (15.0)	8 (6.8)	.193
Death within 24 h postoperation	0 (0)	2 (1.7)	1.000
Neurologic adverse events	5 (12.5)	8 (6.8)	.317
Reoperation for bleeding	1 (2.5)	3 (2.5)	1.000
Initial ventilation time, h	37 ± 59	40 ± 93	.132
Reintubation	3 (7.5)	8 (6.8)	1.000
Pneumonia	2 (5.0)	2 (1.7)	.266
Deep sternal infection	2 (5.0)	2 (1.7)	.266
Lowest eCCr, mL/min	33.0 ± 16.1	53.3 ± 27.1	<.001
Change rate of eCCr, %	−23.4 ± 24.1	−21.5 ± 26.9	.923
Length of ICU stay, d	5.5 ± 9.8	6.2 ± 10.2	.825
Length of hospital stay, d	25 ± 13	28 ± 24	.914

Data are given as number (percentage) or mean ± SD. *eCCr*, Estimated creatinine clearance; *ICU*, intensive care unit.

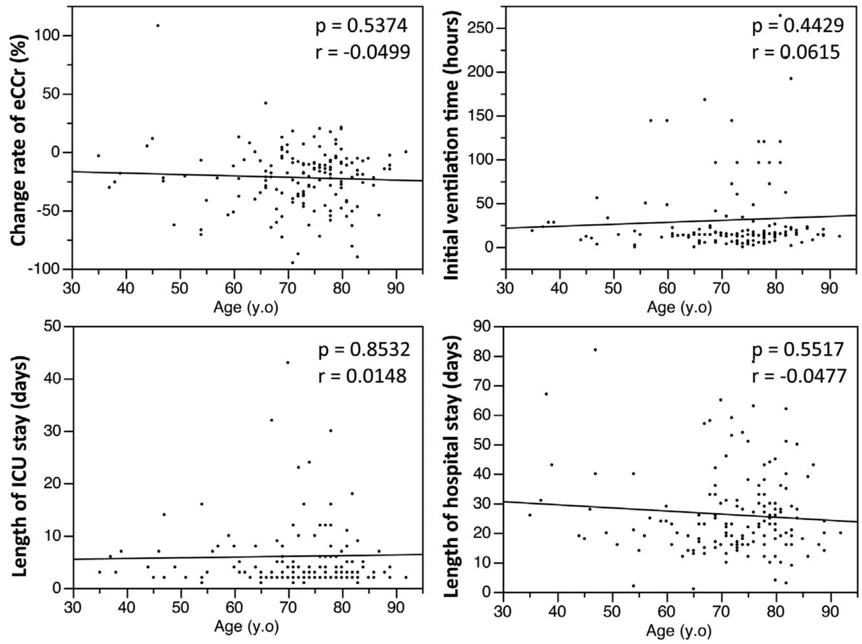

FIGURE 2. The age of patients had no significant correlation with the change rate of estimated creatinine clearance (*eCCr*), ventilation time, and length of intensive care unit (*ICU*) and hospital stay. *y.o*, Years old.

hypothermia of more than 28°C or a modified perfusion technique with balloon occlusion was reported.[15,16] Techniques of open aortic arch repair continue to develop, and open TAR with SACP and HCA can be an effective option for patients with extreme advanced age.

The efficacy of hybrid operation for aortic arch diseases has been reported.[17-19]

Milewski and colleagues[20] reported that hybrid arch repair was a particularly safe alternative to the conventional approach in patients older than 75 years. However, spinal cord ischemia is one of the most severe complications, and the long-term effects of endoleak have not been determined. Complications after hybrid TAR by zone 0 landing are still crucial issues compared with zone 1 landing, and the outcomes are controversial.[21-23] Benedetto and colleagues[24] reviewed 4 studies and reported that hybrid arch repair did not improve operative mortality, but led to an insignificant increase in permanent neurologic disorders and late mortality, compared with conventional aortic arch repair. These reports showed that the selection of patients for hybrid TAR is crucial. In our study, even extreme advanced age (≥80 years) was not a predictor of an adverse postoperative course in open total aortic arch repair with SACP and HCA. Therefore, it is important to evaluate the preoperative conditions of patients properly (ruptured case and consciousness disorder) and determine the optimal surgical strategy for the treatment of aortic arch diseases.

Study Limitations

There were several limitations in this study. First, this study was a retrospective analysis and not a matched comparison. Second, there was a significant difference in etiology between

TABLE 4. Preoperative risk factors for serious adverse complications

	Univariate analysis		Multivariate analysis	
Variables	OR (95% CI)	*P* value	Adjusted OR (95% CI)	*P* value
Aged ≥80 y	2.2 (0.8-5.4)	.113		
Preoperative eCCr <47.3 mL/min	3.6 (1.5-9.5)	.006		
Emergency	2.4 (1.0-6.0)	.055		
Ruptured aorta	9.2 (2.5-35.1)	.001	10.9 (1.8-78.7)	.010
Preoperative consciousness disorder	11.4 (3.3-42.7)	<.001	5.2 (1.1-24.8)	.040
Operative time ≥464 min	3.0 (1.2-7.5)	.017		
CPB time ≥196 min	4.0 (1.1-25.5)	.035		
Circulatory arrest time ≥67 min	2.8 (1.1-8.0)	.032	3.5 (1.1-12.1)	.028
Minimum BT <24°C	3.0 (1.2-7.5)	.018		

Open cells are excluded covariates by multivariate analysis. *OR*, Odds ratio; *CI*, confidence interval; *eCCr*, estimated creatinine clearance; *CPB*, cardiopulmonary bypass; *BT*, body temperature.

TABLE 5. Correlated factors with postoperative length of ICU and hospital stay

Variables	Univariate analysis R^2	Univariate analysis *P* value	Multivariate analysis β	Multivariate analysis *P* value
Correlation with length of ICU stay				
Emergency	0.050	.005		
Ruptured aorta	0.081	<.001	0.282	.001
Axillary artery cannulation	0.048	.006		
Operative time	0.048	.006		
CPB time	0.024	.055		
Minimum BT	0.020	.076		
Correlation with length of hospital stay				
Emergency	0.018	.097		
Ruptured aorta	0.049	.005	0.233	.007
Axillary artery cannulation	0.023	.058		
Operative time	0.035	.019		
Minimum BT	0.039	.013		

Open cells are excluded covariates by multivariate analysis. *ICU*, Intensive care unit; *CPB*, cardiopulmonary bypass; *BT*, body temperature.

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groups E and Y. More ruptured cases were seen in elderly patients, and aortic dissection was mainly seen in younger patients. Therefore, the differences in techniques, including elephant trunk and unilateral axillary artery cannulation, were found between groups E and Y. We cannot deny the influences of the differences on the postoperative course. Third, the relatively small sample size in group E may lead to insignificant differences in mortality and neurologic adverse events. Finally, this study did not include long-term outcomes and comparison with hybrid procedures in patients with advanced age. A matched comparison between conventional open arch repair and hybrid procedures is required to determine the optimal strategy of treatment for aortic arch diseases in high-risk patients.

CONCLUSIONS

Advanced age ($\geq$80 years) was not a risk factor for serious postoperative complications, and age was not associated with an adverse postoperative course. Preoperative consciousness abnormality, rupture, and extended circulatory arrest time ($\geq$67 minutes) were detected as risk factors for postoperative adverse course. Patient selection is crucial, and matched comparison between conventional aortic arch repair and hybrid procedures is required to determine the optimal strategy of treatment for the aortic arch diseases in elderly patients.

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